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SUBJECT: LM Performance Variations  
from LM Center of Gravity  
Movement - Case 320

(NASA-CR-114030) LM PERFORMANCE VARIATIONS  
FROM LM CENTER OF GRAVITY MOVEMENT  
(Bellcomm, Inc.) 20 p

DATE: September 24, 1970

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**MEMORANDUM FOR FILE**

The effects on LM payload capability of increasing or decreasing Descent Stage (D/S) weights in the four payload quadrants were presented to R. A. Petrone on August 27, using the attached figures. The primary effect is a shift in the center of gravity (CG) location which either increases or decreases unusable propellants, which in turn directly affects the LM performance. The LM J-mission configuration (figure 2) was used in all calculations since effects due to LRV weight changes were of prime interest. The most significant propellant system configuration difference between the J and H series is the removal of the propellant tank balance lines and orificing of the branch feed lines for the J-missions (LM-10 and subs).

The geometry-physics of CG effects on propellants is shown by Figures 3 thru 5. For the J-missions, with the thrust vector through an offset CG, a differential head exists between the two tanks. The tank with the larger effective head ( $h_2$ ) will empty faster, and a residual at depletion will develop in the tank with the lower effective head which is directly proportional to the amount of vehicle CG offset.

The change in unusable propellants as a function of CG offset is shown in Figure 6. The unusable oxidizer and fuel can be seen to have sensitivities to CG offset of 43 lbs/in and 20 lbs/in respectively. The number in each quadrant is the sensitivity factor in lb cost/lb added, arrived at by adding one pound in that quadrant [at  $(Y,Z) = 54,54$  inches]. The assumptions and sample calculations for each quadrant are shown in Figures 11 thru 17.

The effect on LM performance of removing the LRV from Quad I or of adding 100 pounds to the LRV is shown in Figure 7. The weight margin is defined as limit weight minus current weight. The point is made that an increase or decrease in current weight which shifts the vehicle CG location increases or decreases unusable propellants. This propellant change will either increase or decrease the limit weight by an amount different than the change in Quad I weight, as indicated in the bottom portion of Figure 7.

SUMMARY

LM performance is significantly affected by payload weight changes which shift the vehicle CG location. The sensitivity factors from Figure 6 show a range of .72 to 1.4 pounds cost per pound added at the points selected in our example. The removal of the LRV (484.06 pounds) from quadrant I (Figure 7) shows an increase in weight margin of only 299.2 pounds, indicating a significant loss in LM performance due to CG shift and the increase in unusable propellants.

The CG factor and its effects on unusable propellants should be considered when weight changes are reviewed. The effect on LM performance may be an important factor in the decision process.

*D.M. Duty*  
D. M. Duty

2032-DMD-meh

**FIGURE 1**

**LM CENTER OF GRAVITY  
PERFORMANCE EFFECTS**

## J-MISSION LM DESCENT STAGE CONFIGURATION

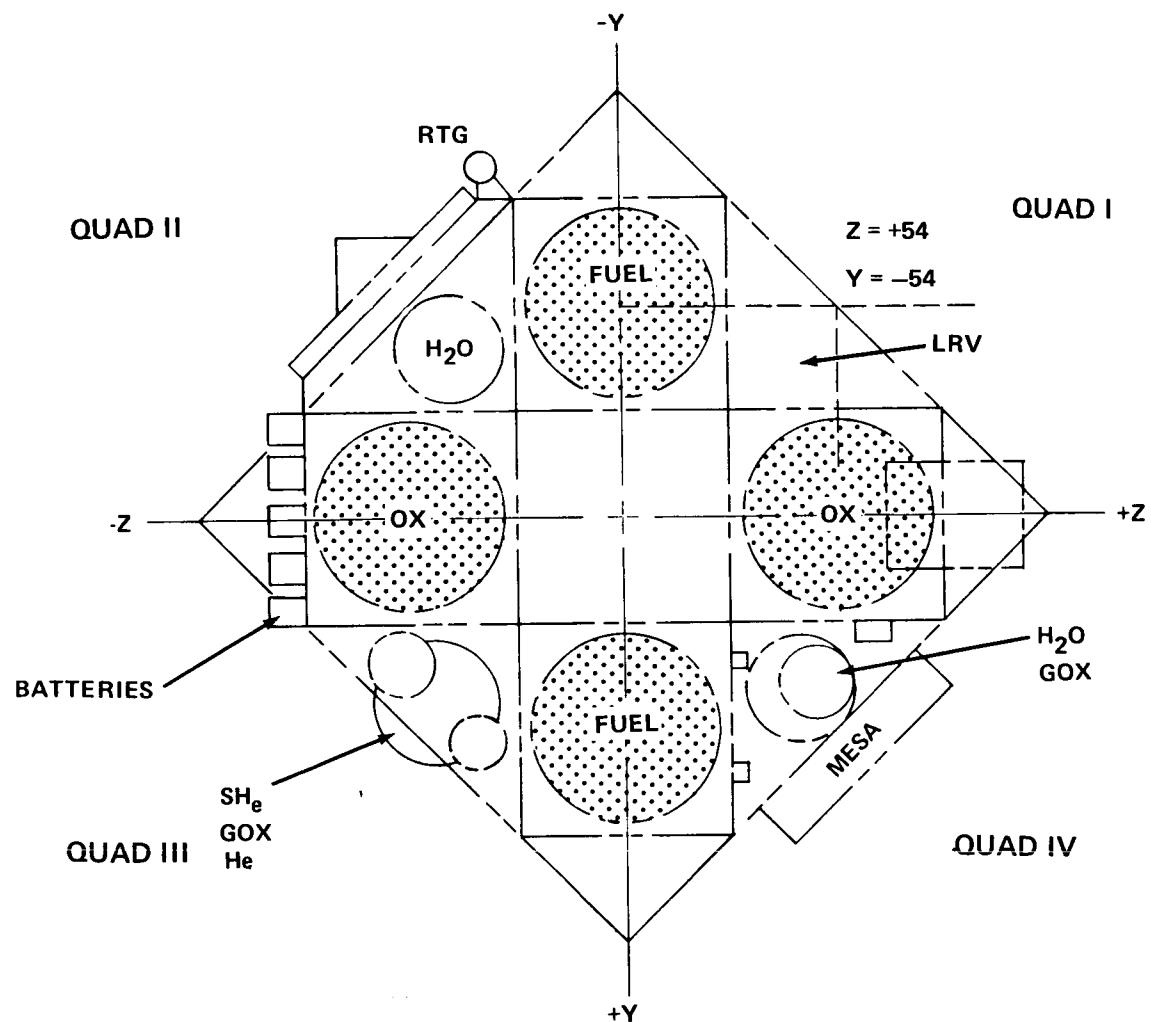


FIGURE 2

J-MISSION

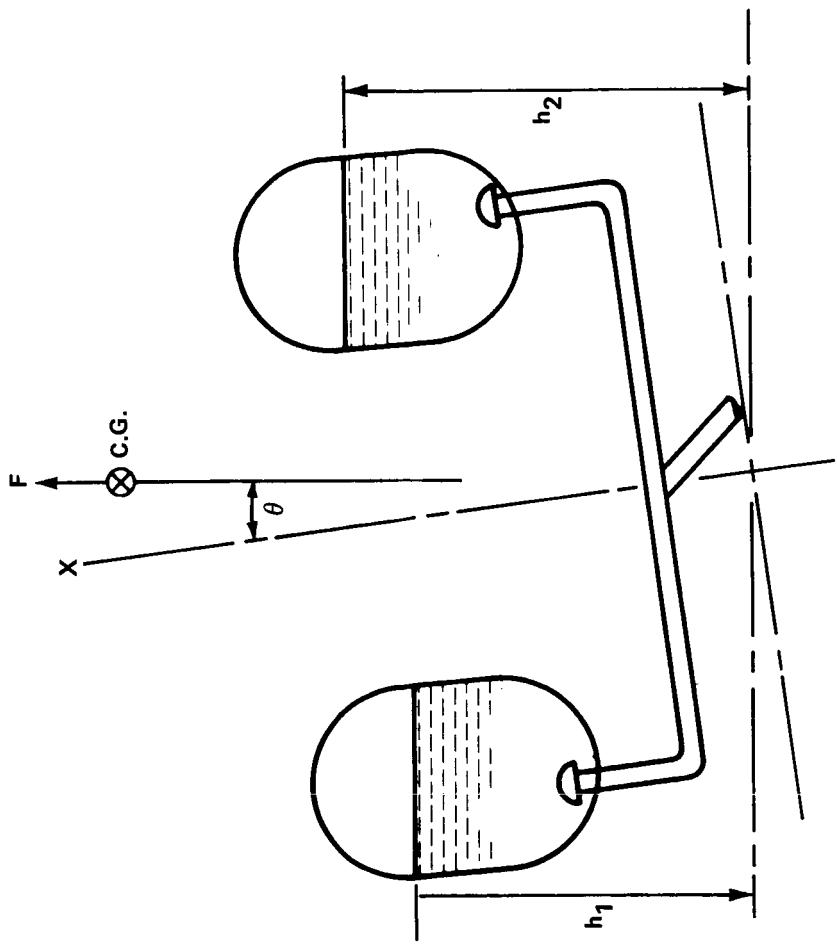


FIGURE 3

## H-MISSION

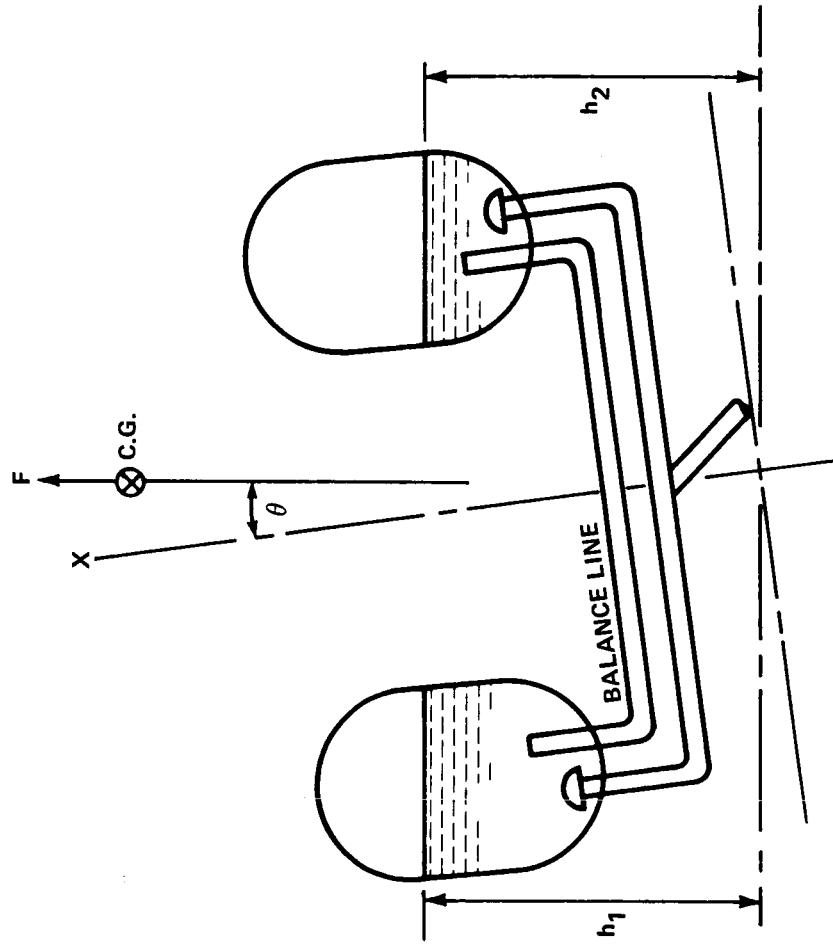


FIGURE 4

**GEOOMETRY-PHYSICS OF C.G. EFFECTS ON  
LM PAYLOAD CAPABILITY**

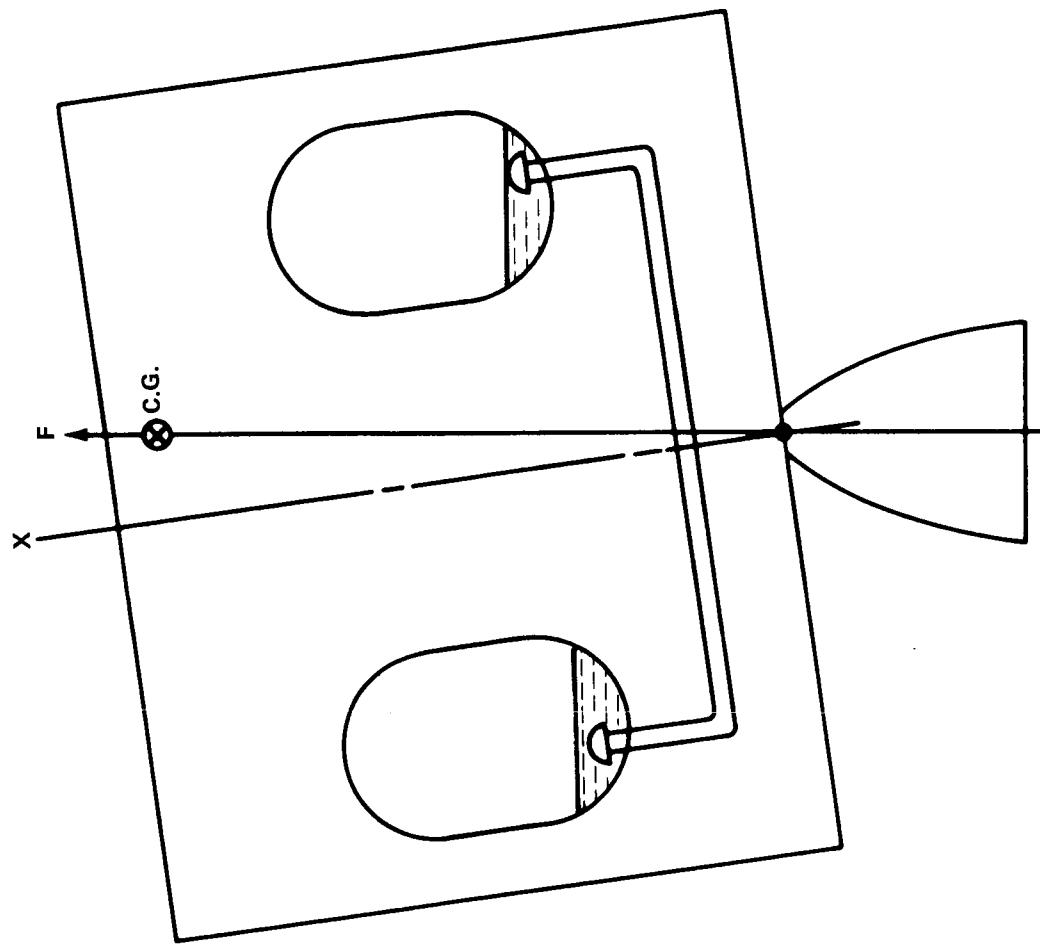


FIGURE 5

**UNUSABLE PROPELLANTS RELATIVE TO CG MOVEMENT  
SENSITIVITY FACTORS (LB COST/LB ADDED) WITH LM 10 CG**

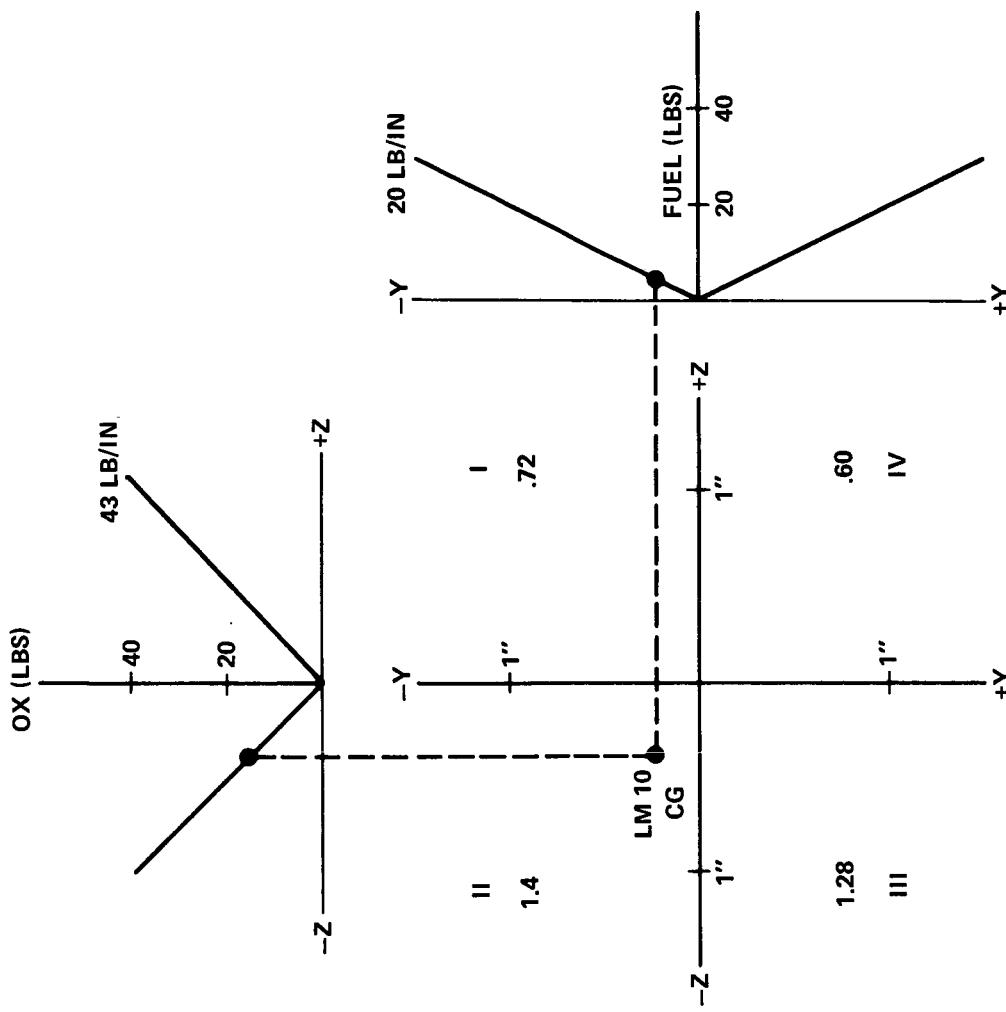
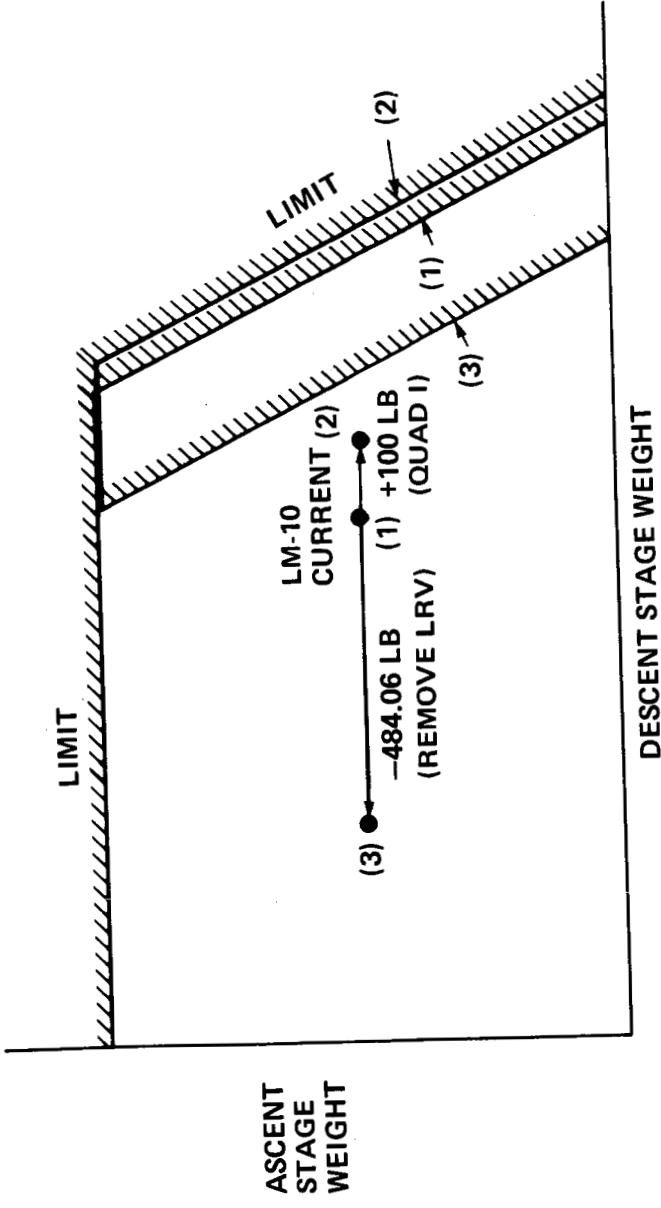


FIGURE 6

## LM PERFORMANCE



WEIGHT MARGIN = LIMIT WEIGHT - CURRENT WEIGHT

$\Delta$  WEIGHT MARGIN =  $\Delta$  LIMIT WEIGHT -  $\Delta$  CURRENT WEIGHT

(1)	CURRENT			
(2)	ADD 100 LB:	-72.2 LB	=	+27.8 LB
(3)	REMOVE LRV:	+299.2 LB	=	-184.86 LB

(+100 LB)  
(-484.06 LB)

FIGURE 7

**PERFORMANCE EFFECTS  
LRV REMOVAL**

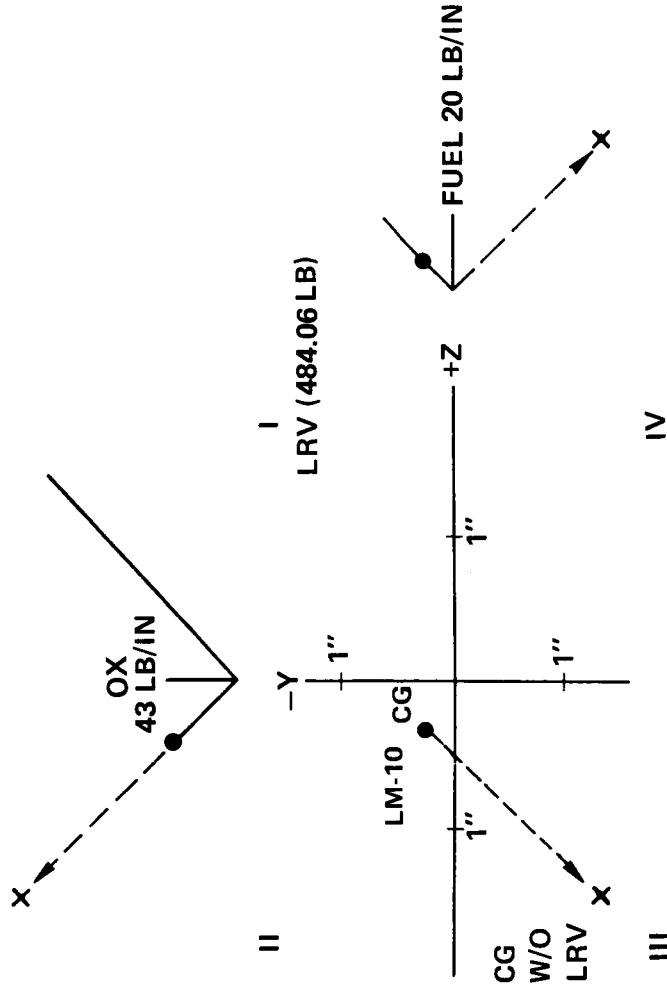


FIGURE 8

## SUMMARY

- PAYLOAD CHANGES WHICH SHIFT THE LM CG WILL HAVE VARYING PERFORMANCE EFFECTS.

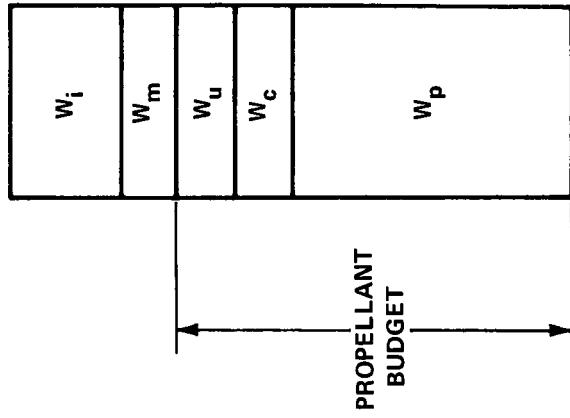
DEPENDING ON:

- 1 – PRESENT CG LOCATION
- 2 – LOCATION OF CHANGE

- WITH THE PRESENT LM-10 CG AND CHANGING LRV WEIGHT, PERFORMANCE SENSITIVITY (WEIGHT MARGIN) IS .72 POUNDS PER POUND ADDED
- MAINTAINING THE LM CG AT THE STAGE CENTERLINE IS IDEAL.  
GAC IS USING A ONE INCH CIRCLE

FIGURE 9

## PROPELLANT BUDGET DEFINITIONS



$w_i$  - ASCENT AND DESCENT STAGE WEIGHTS

$w_m$  - MARGIN (PROPELLANT LOADED MINUS PROPELLANT BUDGET)

$w_u$  - TRAPPED & UNUSABLE PROPELLANT

$w_c$  - LOW LEVEL ALLOWANCE, ABORT RESERVE AND  $3\sigma$   
DISPERSION ALLOWANCE

$w_p$  -  $\Delta V$  PROPELLANT REQUIRED TO LAND  $w_i + w_m + w_u + w_c$

$w_p + w_m$  - PROPELLANT AVAILABLE FOR  $\Delta V$

FIGURE 10

## PAYOUT CAPABILITY AND RESIDUAL PROPELLANT

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### ASSUMPTIONS

- 1 - FULL OXIDIZER TANKS
- 2 - LOAD/OFF-LOAD FUEL TO MAINTAIN MIXTURE RATIO
- 3 - VEHICLE C.G. (Y, Z) = (-0.2, -0.4) INCHES (QUAD II)
- 4 - C.G. SENSITIVITY = .003 INCHES IN (Y, Z) PER POUND ADDED ( $\Delta W$ )  
$$Y = 54''$$
$$@$$
$$Z = 54''$$
- 5 - RESIDUAL FUEL/OX SENSITIVITY TO C.G. MOVEMENT  
IN ANY PAYLOAD QUADRANT
- 6 - ADD 100 POUNDS TO LRV (QUAD I)  
$$\text{FUEL} = 20 \text{ LB/IN}$$
$$\text{OX} = 43 \text{ LB/IN}$$
$$@ (Y,Z) = (-54, +54) \text{ INCHES}$$

FIGURE 11

## CALCULATIONS

1 - ADDITIONAL INERT WEIGHT ( $\Delta W_i$ ) = 100 LBS

2 - PROPELLANT CHANGE DUE TO C.G. SHIFT

$$\text{USABLE OX} = + 12.9 \text{ LBS} \quad (100 \times 0.0003 \times 43)$$

$$\text{USABLE FUEL} = - 6.0 \text{ LBS} \quad (100 \times 0.0003 \times 20)$$

3 - FUEL LOADING DUE TO:

MIXTURE RATIO FOR 12.9 LBS OX = + 8.0 LBS

DIRECT C.G. EFFECT	= + <u>6.0 LBS</u>
TOTAL	14.0 LBS

4 - MARGIN PROPELLANT ( $W_m$ ) CHANGE

$$\text{C.G. EFFECT} \quad = + 12.9 \text{ LBS OX}$$

$$\text{FUEL LOADING FROM (3)} \quad = + \underline{8.0 \text{ LBS F}}$$

$$\text{TOTAL} \quad + 20.9 \text{ LBS}$$

5 - PROPELLANT ( $W_p$ ) REQUIRED FROM MARGIN PROPELLANT ( $W_m$ ) TO LAND:

$$\Delta W_i \text{ FROM (1)} \quad = \frac{100}{2} = + 50 \text{ LBS}$$

$$\text{ADDITIONAL FUEL FROM (3)} \quad = \frac{14.0}{2} = + \underline{7 \text{ LBS}}$$

$$\text{TOTAL} \quad + 57 \text{ LBS}$$

FIGURE 12

**6 - NET CHANGE IN MARGIN PROPELLANT ( $W_m$ )**

FROM (4):	+ 20.9 LBS
FROM (5):	<u>- 57 LBS</u>
TOTAL	- 36.1 LBS

**7 - EQUIVALENT CHANGE IN D/S PAYLOAD CAPABILITY (WITHOUT C.G. EFFECTS)**

$$\begin{aligned} &= 2 W_m \\ &= 2 (-36.1) = -72.2 \text{ LBS} \end{aligned}$$

OR ADDING 100 LBS TO THE LRV IN QUAD I WITH THE C. G. IN QUAD II IS EQUIVALENT TO ADDING 72.2 LBS DUE TO THE CHANGE IN USABLE PROPELLANTS

**FIGURE 13**

## PAYOUT CAPABILITY AND RESIDUAL PROPELLANTS

	INERT ( $W_i$ )	MARGIN ( $W_m$ )	UNUSABLE ( $W_u$ )	REQUIRED ( $W_p$ )
ADD LRV $\Delta$ - QUAD I	+100			
PROP. REQ'D. FOR LRV $\Delta$		-50		+50
C. G. EFFECTS		+12.9 OX - 6.0 FUEL	- 12.9 OX + 6.0 FUEL	
FUEL LOADED FOR OX		+ 8.0		
FUEL LOADED FOR FUEL		+ 6.0		
PROP. REQ'D. FOR FUEL		- 7.0		+ 7.0
RESULTS	+100	-36.1*		+57

\*EQUIVALENT PAYLOAD =  $2W_m = -72.2$  LBS

FIGURE 14

PAYOUTLOAD CAPABILITY AND RESIDUAL PROPELLANTS

<u>-OX -FUEL LBS</u>	<u>INERT (W<sub>i</sub>)</u>	<u>MARGIN (W<sub>m</sub>)</u>	<u>UNUSABLE (W<sub>u</sub>)</u>	<u>REQUIRED (W<sub>p</sub>)</u>
ADD W <sub>i</sub> Δ QUAD II	+ 1.0			
PROP. REQ'D. FOR W <sub>i</sub> Δ		-.5		+.5
C. G. EFFECTS		-.129 OX -.06 FUEL		+.129 OX +.06 FUEL
FUEL LOADED FOR OX		-.08		
FUEL LOADED FOR FUEL			+.06	
PROP. REQ'D. FOR FUEL			-.01	
RESULTS			-.699*	+.49

\* EQUIVALENT PAYLOAD = 2 W<sub>m</sub> = -1.40 LBS

FIGURE 15

PAYOUT CAPABILITY AND RESIDUAL PROPELLANTS

$-OX$ $+F$ LBS	INERT ( $W_i$ )	MARGIN ( $W_m$ )	UNUSABLE ( $W_u$ )	REQUIRED ( $W_p$ )
ADD $W_i \Delta$ QUAD III	+1.0			
PROP REQ'D. FOR $W_i \Delta$	-.5			+.5
C.G. EFFECTS	-.129 OX +.06 FUEL		+.129 OX -.06 FUEL	
FUEL LOADED FOR OX	-.08			
FUEL LOADED FOR FUEL		-.06		
PROP. REQ'D. FOR FUEL		+.07		-.07
RESULTS	+1.0	-.639*		+.43

\*EQUIPMENT PAYLOAD =  $2 W_m = -1.28$  LBS.

FIGURE 16

PAYLOAD CAPABILITY AND RESIDUAL PROPELLANTS

+OX +FUEL LBS.	INERT ( $W_i$ )	MARGIN ( $W_m$ )	UNUSABLE ( $W_u$ )	REQUIRED ( $W_p$ )
ADD $W_i \Delta$ QUAD IV	+ 1.0			
PROP. REQ'D. FOR $W_i \Delta$	-.5			+ .5
C. G. EFFECT	+ .129 OX + .06 FUEL		-.129 OX .06 FUEL	
FUEL LOADED FOR OX		+ .08		
FUEL LOADED FOR FUEL			-.06	
PROP. REQ'D. FOR FUEL			-.01	+ .01
RESULTS	+ 1.0		-.301*	+ .51

\*EQUIVALENT PAYLOAD =  $2 W_m = -.60$  LBS.

FIGURE 17

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Subject: LM Performance Variations  
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Movement - Case 320

From: D. M. Duty

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